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Final Report
on
NASA Grant NAGW5-1412

Phase-B Activities
for the
Large Isotope Spectrometer for Astromag

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Abstract: This is the final report on work funded by NASA grant NAGW5-2168 entitled "Phase-B Activities for the Large Isotope Spectrometer for Astromag". This grant was originally funded to cover the period from September 15, 1990 to October 15, 1991. Following this a series of supplements extended it to 4/16/92.

Introduction: In 1989, after extensive study (Ormes et al. 1986), the Astromag Superconducting Magnet Facility was selected for flight on the Space Station, including three experiments, Wizard, LISA, and SCIN-MAGIC. The Large Isotope Spectrometer Experiment (LISA) was a collaborative effort involving Goddard Space Flight Center (with Jon Ormes as Principal Investigator), Caltech, Washington University, the University of Chicago, and the Danish Space Research Institute. The Space Radiation Laboratory at Caltech was to have primary responsibility for the Cherenkov subsystem.

The scientific objectives of the LISA experiment (see Mewaldt and Ormes, 1987; Binns et al. 1989) are to (1) extend measurements of the isotopic composition of cosmic ray elements from Be to Ni ($Z = 4$ to 28) into the energy range beyond 1 GeV per nucleon; (2) to measure the energy spectra of heavy elements up to energies >100 GeV/nucleon with good statistical accuracy, and (3) to search for heavy anti-matter with $Z > 2$ in cosmic rays.

In 1990, following their selection, the three Astromag instruments were funded to begin Phase-B definition studies. This particular grant (NAG5-1514) focused on defining the Cherenkov subsystem of the LISA experiment, and was part of a larger effort involving the other institutions involved in LISA. This study was proceeding, on schedule, when NASA began to rethink its use of the Space Station.

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In 1991, following a major redefinition of the Space Station, Astromag and a number of other payloads were indefinitely suspended from consideration from flight on Freedom when the Space Station was descoped. Subsequent to this, the funding from this grant was refocused on supporting a new study, directed by Goddard Space Flight Center, whose goal was to determine whether the objectives of Astromag could also be carried out by a free-flying mission launched by an Atlas-IIAS rocket (see, e.g., Ormes et al. 1990). The results of this study were reported in a two-volume study released by GSFC in 1992.

The Phase-B efforts for this Grant included the following activities and developments.

1) Definition of the LISA Cherenkov Counters for the Space Station Version of Astromag: For orientation, Figure 1 shows a cross section of the LISA experiment for the Space Station version of Astromag. The key subsystems are the magnet, the tracking system, the Cherenkov system, consisting of a number of modules, and the TOF system. The Cherenkov subsystem included 24 counters divided into eight identical modules, each consisting of a "trigger counter" with a Pilot-425 radiator, and two velocity-measuring counters, using aerogel radiators with indices of $n=1.03$ and $n=1.04$.

Details of the technical definition of the LISA Cherenkov subsystem for the Space Station are contained in an attached document: "LISA Cherenkov Subsystem IRD" dated 9/21/90, that summarizes the design, required resources, and various other properties of the Cherenkov System. The system weighed a total of 722 kg, and required 110 W of regulated power.

2) Photomultipliers: The LISA Cherenkov design was based on the extensive use of 5" Fine Mesh photomultipliers that could be used in high magnetic field of several kiloGauss. The Hamamatsu Corp. had marketed 2-inch versions of this PMT; for LISA they had developed a new 5-inch version. SRL successfully tested the first model of this new design using magnetic fields and heavy ion beams at the Lawrence Berkeley Laboratory.

3) Aerogel Radiator Development: The Cherenkov radiators for LISA were to be made of large area $\sim 40 \times 40 \text{ cm}^2$ aerogel blocks with indices of refraction from ~ 1.03 and ~ 1.04 . Prototype blocks were obtained from Airglass Inc. in Sweden and successfully tested using ground level muons, and in a balloon borne experiment (Labrador et al. 1993). A prototype counter mounted with 3-inch PMTs, and a radiator with an index of $n=1.043$ achieved

~12 photoelectrons from a minimum ionizing particles. A new method was developed to mount these aerogel blocks in a light-weight frame that enabled them to survive both balloon launch & landings, and numerous truck rides (see Labrador et al. 1993). Methods were also developed to map the thickness and index of refraction of these large area blocks.

The status of various elements of the Cherenkov subsystem at the end of this study is summarized in Table 1.

4) Studies in Support of an Astromag Free-Flyer: Once Astromag was indefinitely postponed from flight on the space station, studies began in earnest to see whether the science objectives could be accomplished with a somewhat smaller Astromag launched on as a free flyer on an Atlas II-AS launch vehicle. Figure 2 compares the Space Station and Atlas designs, while Figure 3 shows more detail of the Atlas design for LISA. In Table 2 critical parameters of the designs are compared, while Table 3 shows the impact on the Cherenkov subsystem. In its original configuration, LISA was limited to particles greater than ~2 GeV/nucleon by the 28.5 deg orbit of Freedom. As a free flyer, Astromag would no longer be restricted to low latitudes. As a result, the reduced yield implied by a smaller experiment could, to a large extent, be compensated for by the more favorable orbit. Figure 4 shows the orbit-averaged energy spectra for several possible orbits.

Tables 4, 5, and 6 and Figures 5 and 6 compare the ability of the two designs to address the three major objectives of LISA. Note that with a higher inclination orbit, a smaller Astromag can still obtain sufficient statistical accuracy to accomplish the major objectives. An important advantage of a high-latitude orbit is that allows isotopic studies over a much wider range of energies than did the original Astromag orbit. By choosing aerogel radiators with several indices of refraction from ~1.1 down to ~1.025, the range from ~1 to ~4 GeV/nuc can be covered. Figure 7 shows the expected isotope resolution for the two designs. Although the somewhat smaller MDR of the Atlas version would limit somewhat the mass resolution of heavier isotopes at high energy, this is more than compensated for by the greater yield and energy coverage in a high-latitude orbit..

Summary: Although this and other Phase-B definition studies for Astromag did not lead to a hardware development phase for Astromag, because of programmatic considerations that resulted in a redefinition of the role of science on the space station, these studies, including this one, must, however, be called very successful. They demonstrated that not only can Astromag science in general,

(including LISA science in particular) be accomplished on the space station, but these objectives can also be accomplished with a free-flying Astromag. Indeed, in many ways the free-flying version of Astromag is superior because it could be put into a higher inclination orbit and cover a broader energy range. Although there has never been a large magnetic spectrometer in space, some day there will be, because it offers unique advantages for exploring a variety of objectives in high energy astrophysics.

Presentations: In March 1991 a presentation on Astromag as a free flyer was made to the NASA Cosmic Ray Program Working Group. On May 2, 1991 a one-hour presentation on Astromag as a free-flyer was made at NASA HQ by R. A. Mewaldt to a meeting of the NASA Space Physics Subcommittee, chaired by George Siscoe. During the 21st International Cosmic Ray Conference held in Dublin during August, 1991, a presentation on Astromag as a free-flyer was made by R. A. Mewaldt.

References

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Ormes, J. F., M. H. Israel, M. E. Wiedenbeck, and R. A. Mewaldt, The Particle Astrophysics Magnet Facility ASTROMAG, August, 1986.

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Figure Captions

Figure 1: The Space Station version of the LISA experiment for Astromag

Figure 2: Comparison of the Space Station and Atlas versions of the LISA experiment.

Figure 3: Details of the Cherenkov subsystem for the Atlas Version.

Figure 4: Orbit averaged energy spectra for a typical element such as oxygen in 57 deg and 28.5 deg orbits.

Figure 5: Energy range over which the Space Station and Atlas versions of Astromag could achieve the LISA science objectives.

Figure 6: Expected yields of nuclei for the SSF and FF designs.

Figure 7: Expected isotope resolution as a function of energy for the Space Station and Free Flyer versions of LISA.

LISA Critical Design Parameters

Parameter	Space Station	Free Flyer
Mass	1800 kg	885 kg
Power	840 watts	380 watts
Bit Rate	9 kbps ave 30 kbps peak	8 kbps ave 20 kbps peak
Geometry Factor	0.09 m ² sr	0.03 m ² sr
Maximum Detectable Rigidity (R _{max})	3.2 TV	2.4 TV
Field of View	110° x 15° fan	90° x 20° fan
Mission Duration	2 yr	2 yr
Size	4.5m diameter 1m depth	3.5m diam. cylinder 1m depth

Cerenkov Subsystem Changes in Adapting to Free Flyer

Change	Free Flyer	SSF Proposal	Impact
Number of Segments	5	8	Reduced Size, Complexity, and Geometry Factor
Number of Counters	$5 \times 3 = 15$	$8 \times 3 = 24$	Reduced Size, Complexity, and Geometry Factor
Active Area of Counters	$\sim 50 \times 50$ cm^2	84×42 cm^2	Reduced Machining; More Convenient Size
Number of PMTs/ Counter	6	10	Reduced Complexity
Indices of Refraction			
Pilot - 425	1.5	1.5	Broader Energy Range;
Aerogel	1.025, 1.05, 1.09, 1.15	1.03, 1.04	More Complexity; Sintering required for
Teflon	1.34	-	$n > 1.06$ (DSRI)
Field Intensity	1-3 kG	0.5 - 1 kG	Closer to Coil ($\sim 10\%$ effect on PE yield)

Overall modular approach remains, including redundant velocity measurements

Isotopic Composition Measurements with LISA

	<u>Space Station</u>	<u>Free-Flyer</u>
Element Range	$4 \leq Z \leq 30$	$4 \leq Z \leq 30$
Energy Range (GeV/nuc)	2.5 to 4	0.6 to 4
Flux @ 2.5 GeV/nuc	1	~5
Geometry Factor	0.09	0.03*
Yield (1-4 GeV/nuc $_{14}\text{Si}$)	5×10^4	10^5
Mass Resolution		
(average 0.6 to 4 GeV/nuc) C	0.18 amu	0.16 amu
Si	0.20 amu	0.18 amu
Fe	0.25 amu	0.25 amu

*Distributed into 5 separate energy intervals.

High Energy Element Composition and Spectra with LISA

	Space Station	Free-Flyer
Element Range	$4 \leq Z \leq 28$	$4 \leq Z \leq 28$
Charge Resolution (δZ)	0.1	0.1
Maximum Detectable Rigidity ($R_{\max}$) (median values)	3.2TV	2.4TV
Energy Resolution		
@10 GeV/nuc	0.7%	1%
@100 GeV/nuc	6%	8%
Geometry Factor (m^2sr)	0.09	0.03
Energy Range (GeV/nuc)	2 to 800	0.6 to 600
Yields: ${}^{26}\text{Fe} \geq 1 \text{ GeV/nuc}$	2×10^6	2.5×10^6
$\geq 10 \text{ GeV/nuc}$	10^5	3×10^4
$\geq 100 \text{ GeV/nuc}$	2000	700

Anti-Nuclei Search with LISA

	Space Station	Free-Flyer
Element Range	$4 \leq Z \leq 28$	$4 \leq Z \leq 28$
Energy Range	≥ 2 GeV/nuc	≥ 0.6 GeV/nuc
Geometry Factor (m ² sr)	0.09	0.03
Number of Redundant Measurements of Z	8	8
Number of Positions Defining Trajectory	5x, 5y	8x, 8y
Number of $Z \geq 6$ per 2 years		
0.6 to 5 GeV/nuc	2×10^6	8×10^6
0.6 to 100 GeV/nuc	7×10^6	10^7
Sensitivity	$< 4 \times 10^{-7}$	$< 3 \times 10^{-7}$

Cerenkov Subsystem Status

Issues/Concerns

Photomultiplier Tubes

- Performance in high-B field (unshielded)
- Space qualification

Aerogel Radiators

- Availability in large size
- Machining/mounting
- Stability/contamination
- Mapping (thickness, n)
- Light Yield

Contributions from knock-on electrons in large-B field

Status

Photomultiplier Tubes

- First 5" version purchased from Hamamatsu
- Successfully tested to 3 kG (LISA: 1-3 kG)
- Improved, ruggedized version under development

Aerogel Radiators

- Large ($\sim 50 \times 50 \text{ cm}^2$) blocks obtained with $n = 1.025, 1.055$
- New machining, mounting methods developed
- Automated thickness mapping at JPL
- Index mapping with x-rays demonstrated
- Method developed to monitor stability, contaminants (e.g. BaSO_4)
- Bevalac tests performed 12/90
- Aerogel counters to be flown on IMAX balloon experiment ($n=1.025, 1.055$)

Knock-on Electrons

- Analytical/Monte Carlo approaches indicate limited contribution
- Accelerator calibrations planned

SECTION A-A

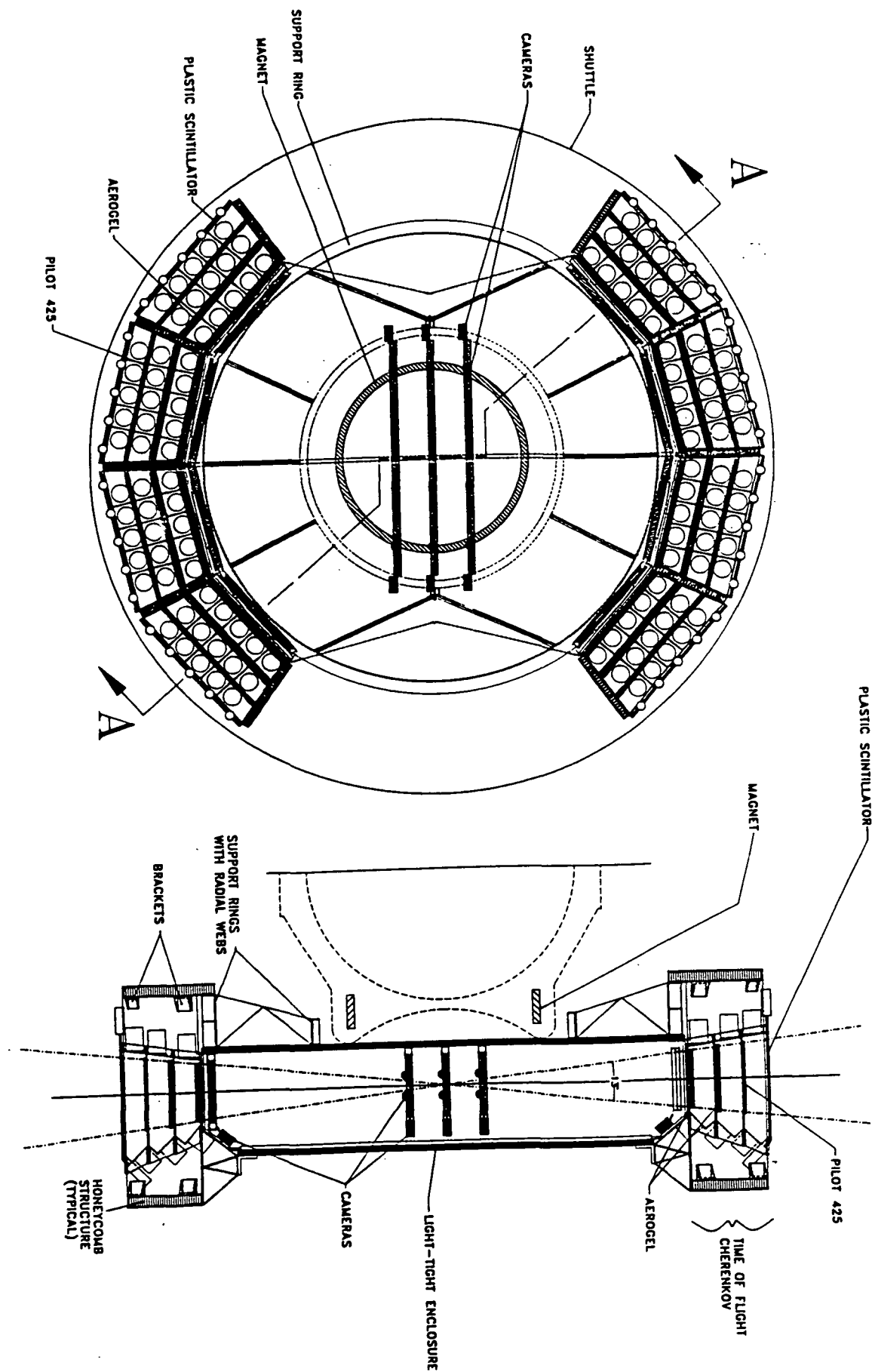
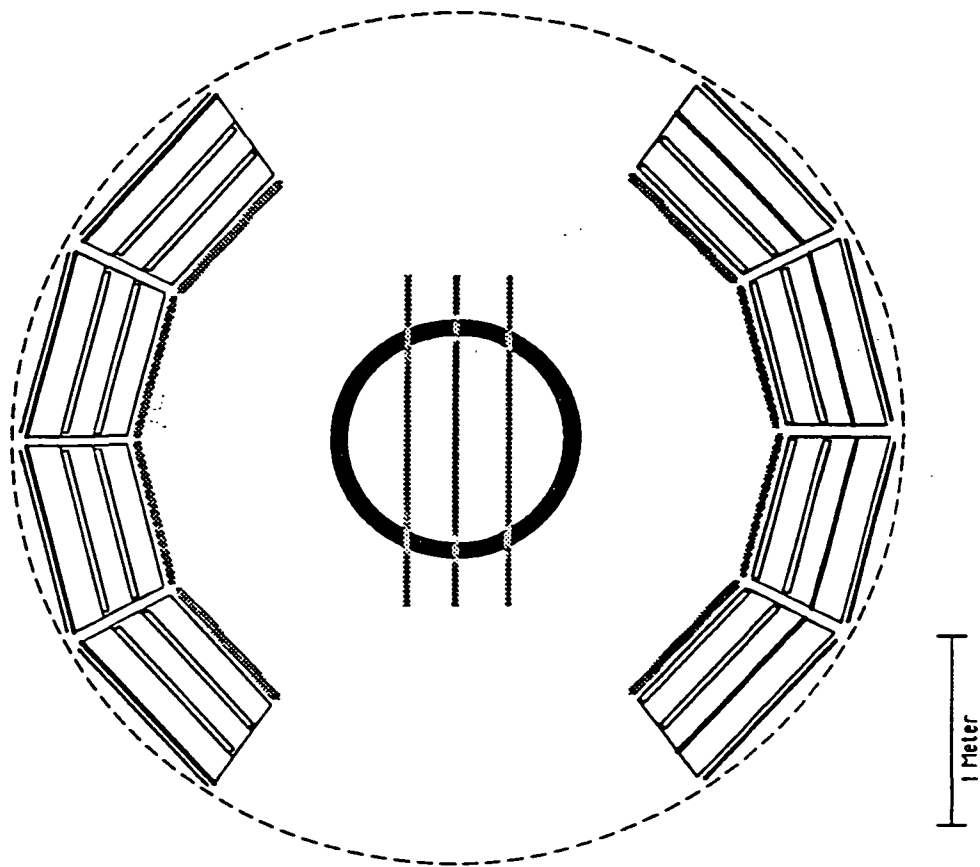


Fig. 1

Space Station Freedom



Free Flyer

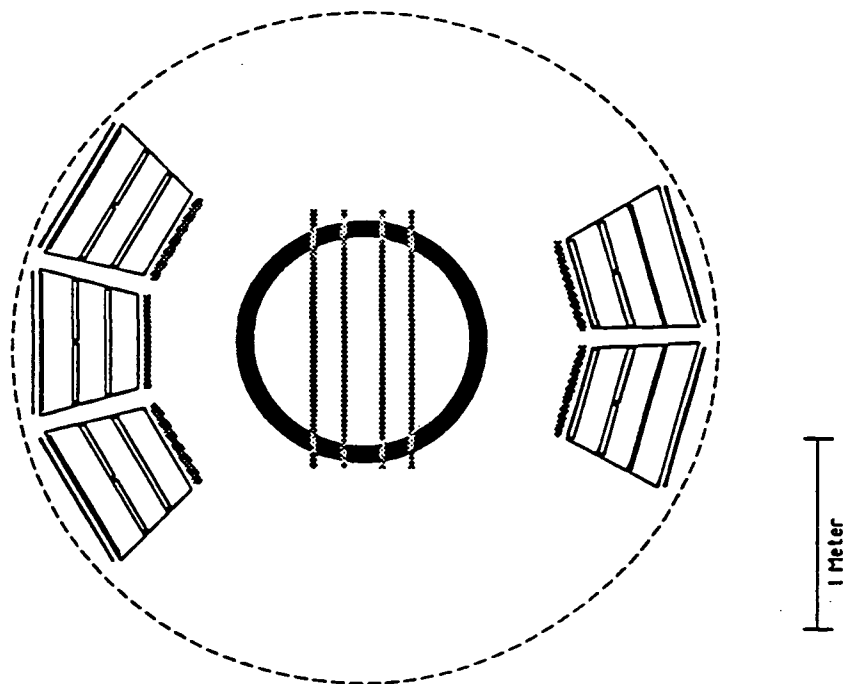


Fig. 2

LISA Free Flyer

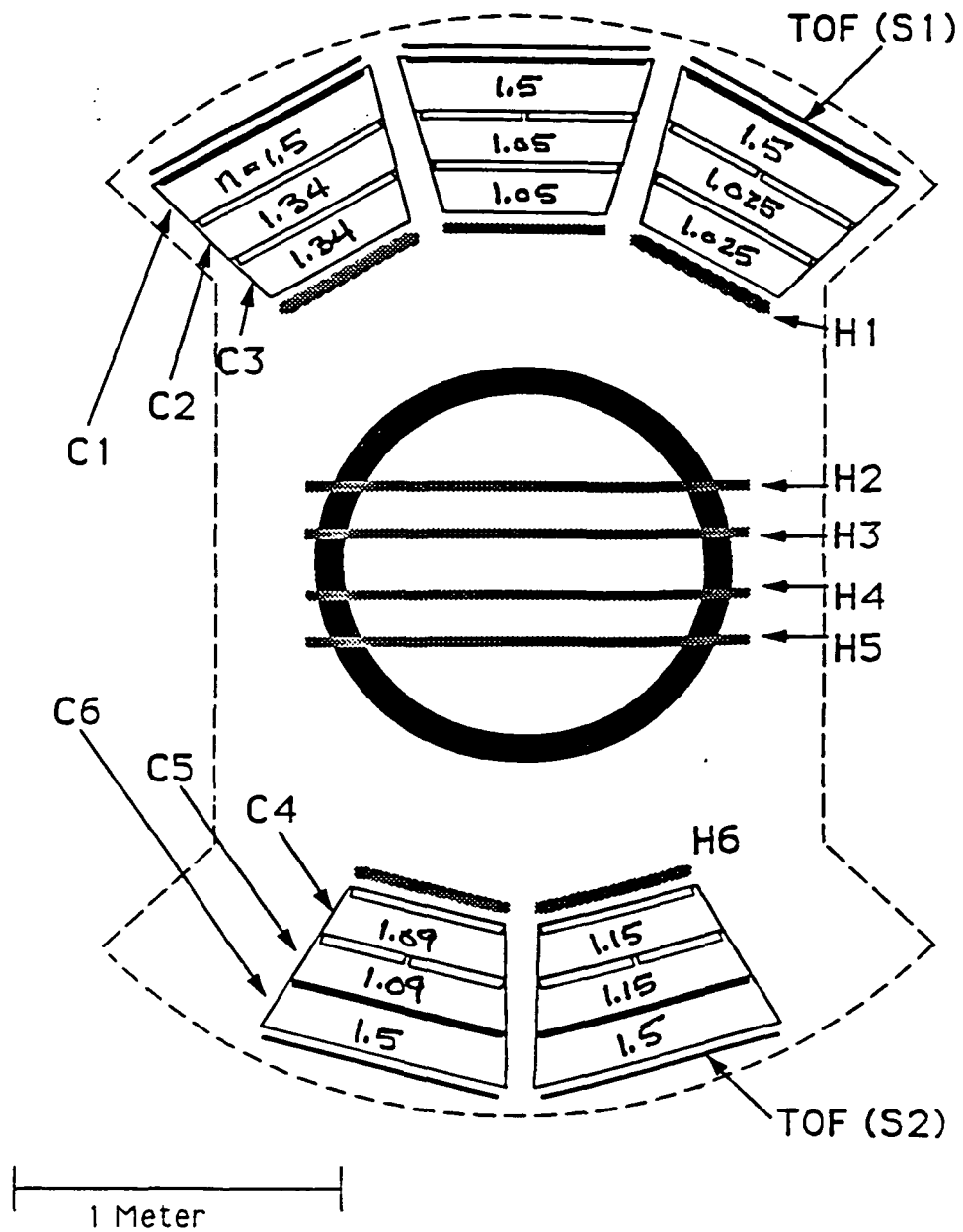


Fig. 3

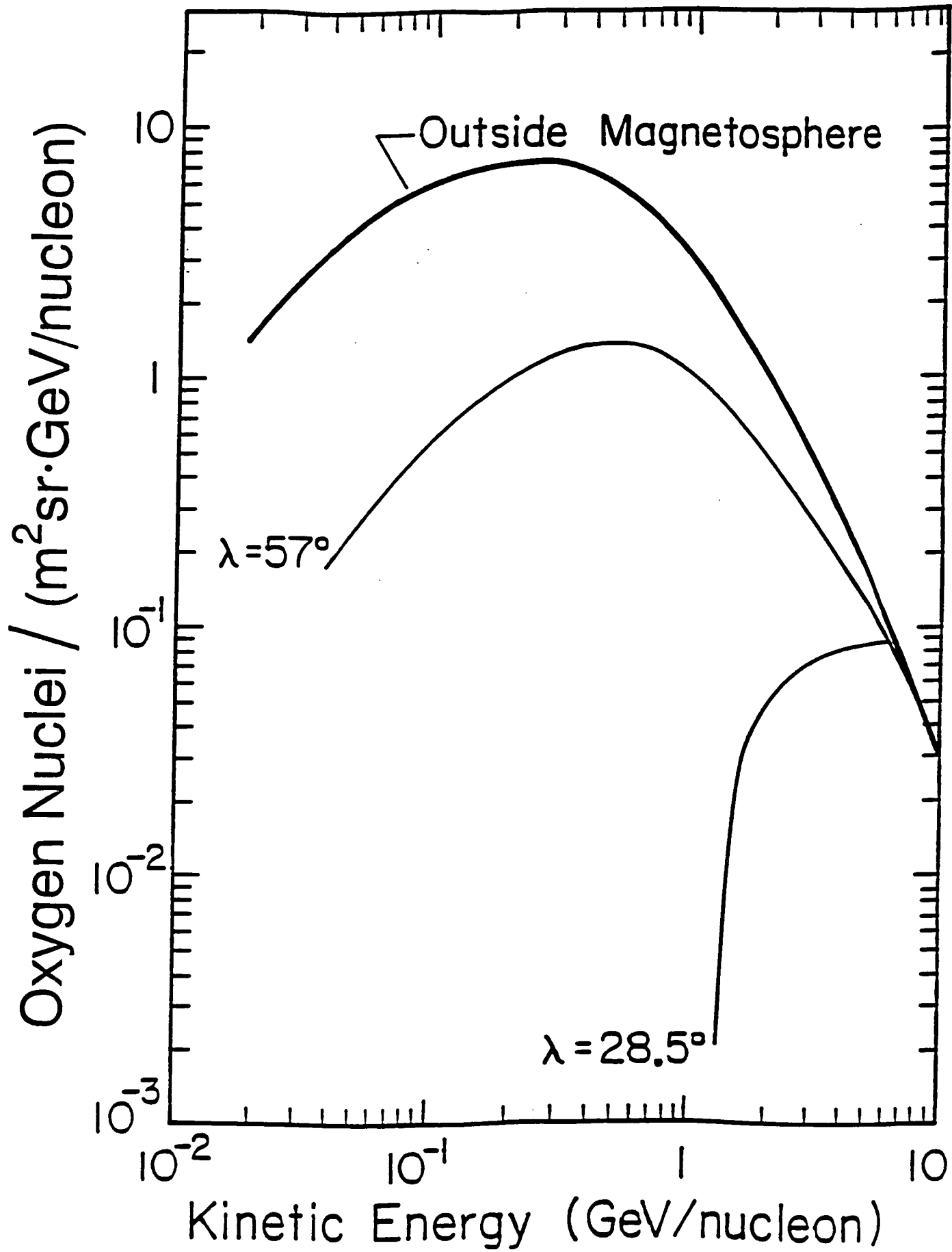


Fig. 4

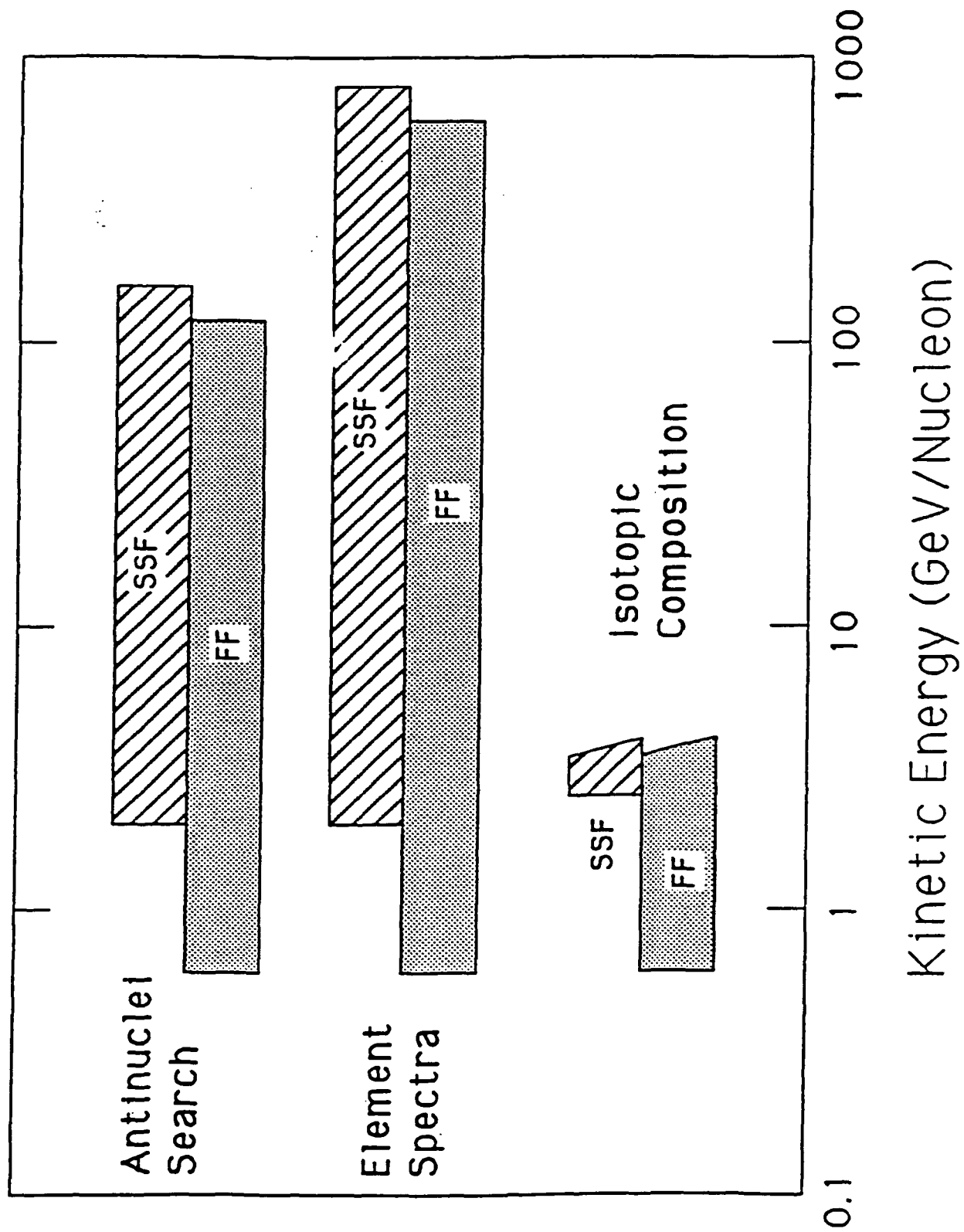


Fig. 5

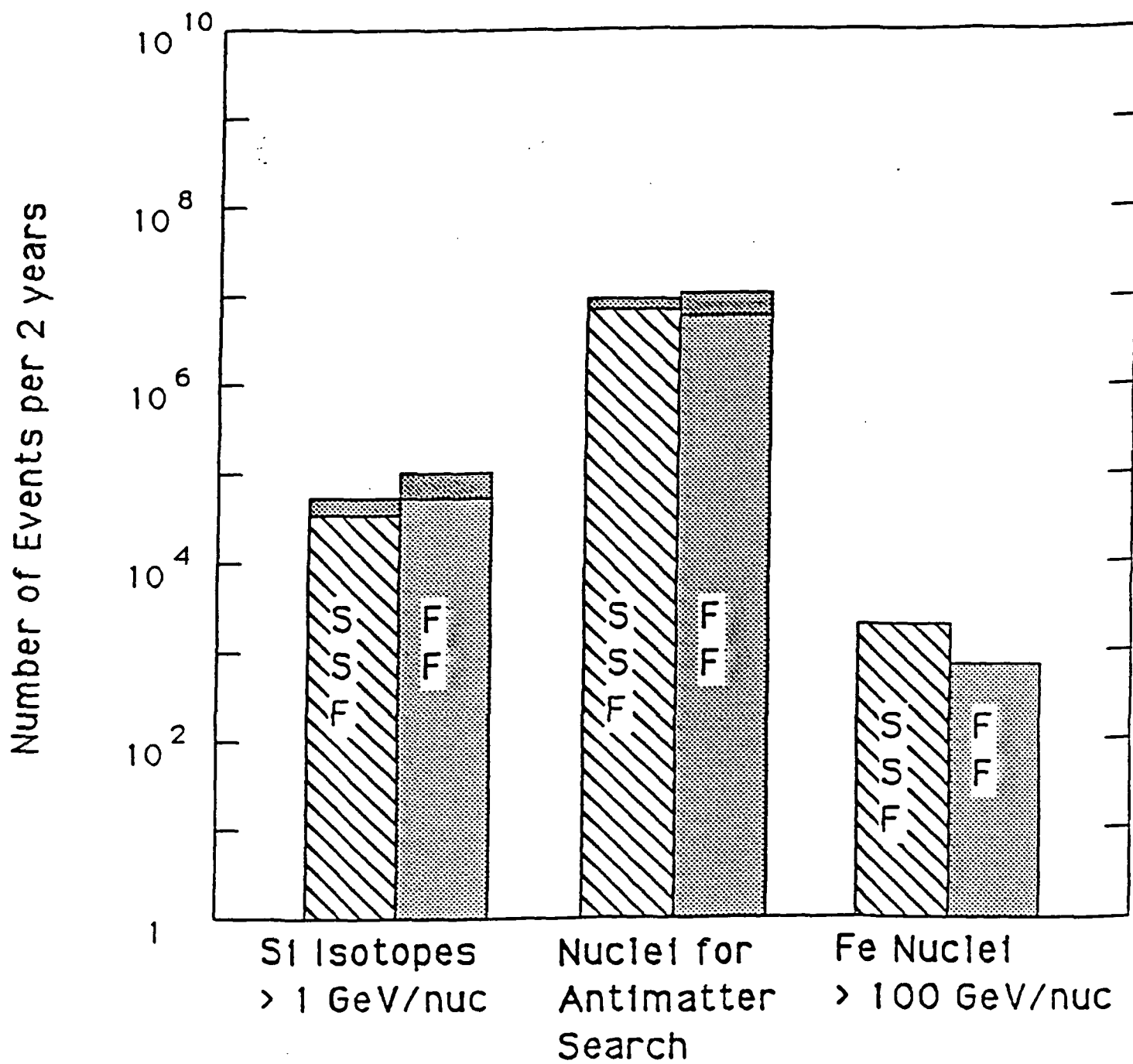


Fig. 6

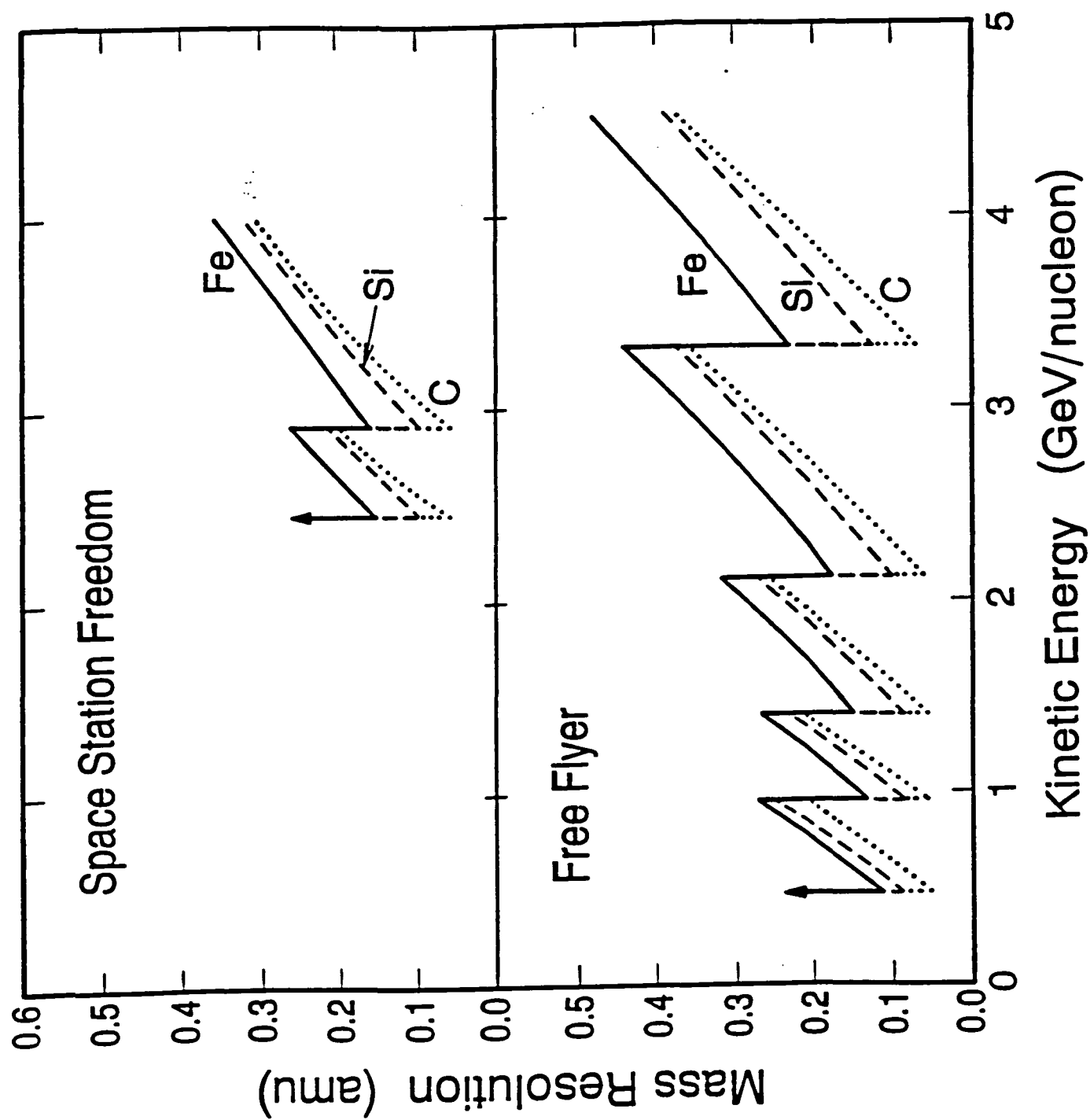


Fig. 7

LISA Cerenkov Subsystem IRD

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1. Type of Detector

Caltech is responsible for the Cerenkov subsystem for LISA, including the Cerenkov counters themselves, and the electronics required to read them out. All 24 of the Cerenkov counters are of similar design, consisting of a radiator and light-integration chamber viewed by ten 5-inch photomultipliers (PMTs).

2. Number of Detectors and Supporting Hardware

The twenty-four Cerenkov counters are divided into 8 identical modules, each consisting of one "trigger counter" containing a Pilot-425 radiator, and two velocity-measuring counters containing aerogel radiators with indices of $n=1.03$ and $n=1.04$ (see Figure 1).

There will be 4 identical boxes containing Cerenkov digital and analog electronics, each box associated with 2 modules (or 6 counters). These will be located in the vicinity of the PMTs. In addition, there will be one central Cerenkov electronics box.

3. Envelope Dimensions for Detectors and Supporting Hardware

The dimensions of the Cerenkov modules are driven by the size of the radiators. Figure 2 shows a side view of one Cerenkov module drawn in 10/88 (prior to the proposal) that is approximately accurate, although somewhat out of date. It shows aerogel radiators that were 40 cm x 80 cm x 3 cm, each composed of two 40x40 blocks. In writing the proposal the assumed size of the aerogel radiators was increased to 42x84. Note that this size can still be accommodated within the Cerenkov boxes shown in Figure 2. The eight Pilot-425 radiators were each assumed to be 90 cm x 50 cm x 1.25 cm in the proposal. There are a few other differences between Figure 1 and 2, such as the size and location of the aerogels, that are discussed below. Another minor correction to Figure 2 is that the Cerenkov tubes should have the shape of cylinders that are about 13 cm in diameter and about 14 cm long.

Since writing the LISA proposal we have done more thinking about how the aerogels might be mounted. Figure 3 illustrates the current concept. Note that surrounding the aerogel block is a frame 2.5 cm wide and a region of interface material about 0.5 cm wide. In addition, we should probably be conservative, and say that the outer 1 cm of the aerogel may not be usable, or might have lower resolution. In addition, we probably need a 1 cm thick interface between the two blocks in a counter, which results in an assumed 3 cm wide "dead layer" down the center of the radiator.

The result of this mounting scheme is that the total dimensions of the frame that houses an aerogel with an "active area" of 42 x 84 will be more like 50 cm x 95 cm.

This size will still fit in the narrow dimension of the box shown in Figure 2, but it would not fit in the other dimension (azimuthal dimension in Figure 1). It now appears that the minimum length of a box housing a 84x42 aerogel would be about 96 cm. As a result, the spacing between the four modules on the top and bottom might have to be increased (see Figure 1).

Figure 4 is a revision of Figure 2 that illustrates the dimensions required for our nominal design. It shows a side view of a module, including aerogels with 84x42 active area and frame. These boxes could still be 18 cm high. Nominal dimensions are given in cm.

In the period since the proposal was written we have also learned that it should be possible to get somewhat larger aerogel blocks. We presently estimate (conservatively) that the largest size available for an index of $n=1.03$ might be about 48 cm x 48 cm, while the dimension of $n=1.04$ might be about 50 x 50. This might translate to "active areas" of 46 x 92 for $n=1.03$ and 48 x 96 for $n=1.04$. To accommodate these larger blocks we would want to increase the size of the Cerenkov boxes accordingly. Coupled with this increase in size it is also desirable to consider going to a design with three modules on top and bottom. Some of these possibilities are discussed in Item #26.

4. Weight Breakdown

Following is the estimated weight breakdown for the Cerenkov subsystem.

Items in One Module	Mass (kg)
Pilot 425 Radiator (50 x 90 x 1.25 cm ³)	6.6
Aerogel Radiators 2 (42 x 84 x 3 cm ³)	3.5
PMTs and Bases (30 x 1.25 kg)	37.5
Cerenkov Boxes (3)	30
Electronics, cabling	12
	89.6 kg per module
8 modules =	717 kg
Central Control Box =	5 kg
Total =	722 kg

Note that the above estimate does not include any structure for mounting the central control box.

5. Field of View Requirements

The field of view of the individual Cerenkov counters considered alone is 4π ; in considering coincidences between the top and bottom halves of LISA the field of view is fan-shaped, as illustrated in Figure 2.

6. Alignment Requirements

The alignment of the Cerenkov subsystem with respect to the rest of LISA and Astromag is not nearly as critical as in the case of the trajectory subsystem. We require to know the position of the radiators with respect to the trajectory system to an accuracy of ~ 1 mm in order to make use of the response maps for each radiator.

We must also know the angle of the radiators with respect to the trajectory system to correct for the pathlength of the particle through the radiator. At a worst case incidence angle of $\sim 45^\circ$ we must know the angle to 0.3° for an error in the apparent thickness of less than 0.5%. Over the 40 cm length of an aerogel block this translates to ~ 2 mm alignment tolerance, comparable to above.

We also require the position with respect to other counters in LISA to an accuracy of a few mm in order to make accurate calculations of the geometry factor.

There is not presently a requirement to know the position of the Cerenkov boxes and radiators with respect to the magnetic field to anything better than 1 cm.

7. Power Requirements

The power budget given below assumes that the Cerenkov electronics provides individual ADC chains for each PMT and is organized, as shown in Figures 5 and 6. A central Cerenkov processor is used for the collection of data and communication with the LISA system electronics.

Per counter:

ADC chains ($350\text{mW} * 10$)	3.5 W
logic, sum amp, etc.	0.5
high voltage	0.5
subtotal per counter	4.5 W

24 counters ($4.5\text{W} * 24$)	108 W
Central Cerenkov Processor	2
Total regulated power (no contingency)	110W
Total unregulated power ($110\text{ W} / 0.75$)	147 W

The present power estimate is about 20 percent lower than our earlier estimate due to: (1) baselining the use of a new low power ADC, the CS5102, which achieves 16 bit resolution, a conversion time of $80\text{ }\mu\text{sec}$, and a power dissipation of only 40 mW, and (2) baselining the operation of the pulse amplification and storage circuitry at modestly lower supply voltages.

8. High Voltage Requirement

The high voltage for the operation of the PMTs in a given Cerenkov module will be generated within its associated electronics module, as illustrated in Figure 5. While the details of the high voltage generation and distribution are TBD, the PMTs are known to require between 2000 and 2600 volts and have leakage currents of 0.1 to $1.0\text{ }\mu\text{A}$. It is likely that two or more HV voltage supplies will be stacked in each module to allow the optimization of PMT bias network currents for minimum power.

9. Low Voltage Requirements

The main needs, given the baseline concept outlined above, are for regulated power of: 10V @ 5A, 5V @ 4A, and -5V @ 6A.

10. Materials List

The following materials are planned for construction of the Cerenkov counters.

- 1) Aluminum Alloy, Type 6061
- 2) Aluminum Alloy, Type 4043
- 3) Stainless Steel, Type 316
- 4) Stainless Steel, Type 303
- 5) Brass Alloy, Designation 716
- 6) Millipore Filter Paper, Type VCWP-0.1; Cat. # S09Q008H0
- 7) Viton Rubber (O-Rings).
- 8) Sylgard Potting Material, Type 184, Dow Corning Corp.
- 9) Sylgard Prime Coat, Dow Corning Corp.
- 10) Tape, Double-Sided; Thickness range 2-5 mils (Isotack tape under investigation)
- 11) Alodine Coating, Per MIL-----
- 12) Aerogel Radiator (Silicon Dioxide).
- 13) Pilot 425 Radiator (basically doped lucite).

In addition, we would be using TBD electronics components and a large number of Hamamatsu photomultiplier tubes of a new design.

11. EMI Requirements

Since the PMTs are to be enclosed in a Faraday cage formed by their housings and the Cerenkov module housing, and all sensitive electronic circuits will be shielded, there will be no special EMI requirements.

12. Thermal Requirements (Heat dissipation)

Operating Temperature Limits -

Preliminary estimates of the temperature limits for the Cerenkov subsystem are as follows:

- Preferred operating temperature: 5 to 10 ° C
- Operating range: -10 to +30 ° C
- Storage range: -10 to +40 ° C

A primary factor driving the operating range of the Cerenkov Counters may be the gain-associated temperature coefficient of the PMTs. While the proposed Hamamatsu 5" PMTs have not yet had this parameter evaluated, the coefficient for a Bialkali Photocathode typically ranges between (plus and minus) 0.1 and 0.5% per ° C (in gain), and will vary from tube to tube within this nominal range. This factor would argue for a relatively temperature- stable operating environment. Temperature stability is more critical on a short time scale (where we desire < 1 ° C change over an orbit) than on a longer time scale (months), where inflight calibrations are possible. However, there are alternate ways to approach this problem, perhaps through the use of active temperature-compensated base designs. Since it is anticipated that in-flight calibration

will be required, the specification of calibration frequency should address the question of anticipated temperature variation coupled with PMT stability.

Heat Dissipation - It is anticipated that no heat will be generated internal to the three Cerenkov Counter housings. The Aerogel materials employed in two of the three counters are very poor thermal conductors, and, in addition, will probably be thermally isolated from the [aluminum] counter housing through internal mounting techniques. No heat dissipation problems are anticipated for the Aerogels (however, see Section 24 on storage/operating temperature requirements for these materials). The third counter employs a Pilot 425 radiator (basically doped lucite), which will also be thermally isolated from the counter housing. No heat dissipation problems are anticipated for this radiator.

Heat generation directly associated with the PMTs will be dependent on the TBD base configuration. The preliminary counter design baselines minimal thermal isolation of the PMTs, simply as a function of design ease, and lack of quantitative data on the PMT thermal sensitivity. In the absence of convection, heat transfer through conduction will occur at some level between the PMT envelope and the counter housing in the current design. Due to thermal stability versus performance questions associated with the PMTs, this area needs to be addressed in more detail. It is possible that increased thermal isolation of the PMTs (with respect to the counter housing) will be required. Note that due to EMI considerations, it may be necessary to fully enclose the PMTs in a conducting envelope, coupled directly to the counter housing (i.e., grounded to the housing). However, techniques are readily available that would permit, if required, thermal isolation of the PMT, even if enclosed in a electrically conducting housing.

13. Grounding Provisions

We presently assume that the Cerenkov counters (24), their associated electronics modules (4), and the central Cerenkov processor (1) will be mounted in close proximity and be grounded to the payload structure through their physical mounts. The required surface area of electrical contact for each box is TBD. We assume that ground currents flowing in the spacecraft structure will be minimized by interface and power isolation techniques, and controlled by requirements levied by the payload upon individual subsystems.

14. Harness Routing Requirements

Cabling from a Cerenkov module electronics box to each of the associated PMTs will include: approximately two shielded HV coax of type TBD, and one signal coax of type TBD. A shielded twisted pair will be needed to connect a thermistor, located at a TBD location on the Cerenkov module, to the electronics box.

Cabling required from the Cerenkov central processor to each of the module electronics boxes will include: one signal coax for the disc. pulse, a small number (TBD, <4) of signal coaxes to distribute timing information to start and stop event processing, a small number (TBD, <5) of wires to serially communicate low speed control and data.

Cabling from the Cerenkov central processor to the LISA system electronics is TBD. Location and distribution of low voltage power is TBD.

15. Assembly Requirements

There are two possible aspects to the LISA assembly sequence - pre-launch and on-orbit. It is presently assumed that LISA will be launched as a complete system, in which case the only on-orbit assembly required is to mate LISA with Astromag. It is not presently anticipated that the Cerenkov detectors will require any on-orbit assembly.

The pre-launch assembly of the Cerenkov Subsystem is based on its modular design - each of the eight identical modules contains three counters. It is expected that each of the 24 individual counters will be assembled and tested separately, including the Cerenkov box with its Millipore high reflectance coating, the radiator, the PMTs, and the electronics. Following qualification of the individual counters, groups of three counters will be assembled into modules, at which time additional testing can be performed. These modules will then be mounted into the LISA support structure, where final testing can take place.

16. Access Requirements/Mechanical Clearances

The preliminary counter design baselines the ability to remove individual PMTs from the counters, without requiring removal of the individual counter or its associated module from the overall mechanical support structure. All PMT mounting hardware is envisioned to be external to the counter, requiring simple hand-tools for removal. It is anticipated that removal of three electrical connectors, and of order four mechanical fasteners, will permit removal of an individual PMT. The PMT is removed from the counter by applying a force to the PMT in a direction normal to the PMT mounting surface on the counter (along the PMT cylindrical axis), and sliding the PMT back approximately 5 cm. For the case of radiator failure (i.e., breakage, contamination etc.) in an individual counter, there are 2 options: 1) Removal of the counter and replacement of the radiator, or 2) Replacement of a complete spare counter. In this case, details of the access requirements and associated mechanical clearances will depend on the configuration the counter is in (e.g., individual module form vs. say the completed instrument). For the case of the completed instrument, access requirements and clearances will depend on the detailed design of the overall mechanical support structure.

17. Housekeeping Telemetry List

Item	#
Temperatures of counters, PMTs, electronics, etc.	≤ 250
High Voltage measurements for each counter	~ 16
Low Voltage measurements	~ 24
Low Voltage current measurements	~ 24

18. Command Requirements

The details of the commanding needs are TBD. However the general desire will be to have a small number of discrete commands such as "power on" and "power off", coupled with a general purpose parallel or serial command interface which would be used to (1) set detector thresholds, (2) adjust PMT voltages, (3) disable individual

PMTs from the trigger sums, (4) initiate or control possible calibration sequences, (5) etc.

19. SAA High Voltage Requirements

Based on our experience on HEAO-3 it may not be necessary to turn the Cerenkov modules off during passage through the SAA. However, if other detectors in LISA are turned off, it might be desirable to consider turning off the Cerenkov detectors. The HEAO HNE (C3) experiment operated its phototubes at about 950 volts to cover the charge range from about 17 to above 100 (with about $0.5 \text{ per tube} \cdot Z^2$ photo-electrons). These tubes were operated through the SAA for 300 days with no evidence of any permanent or transient gain changes after exit from the SAA.

20. Interface Requirements for Mounting Detectors

At some level, interface requirements are coupled with alignment and assembly requirements. We envision a fully pinned assembly/alignment procedure for each of the three counters or detectors making up a single module. This approach only requires proper pin placement on each counter during initial fabrication to achieve proper interface positioning of the counters relative to one-another when assembled into module form; relative counter positioning in each module would be readily held to the sub-millimeter level with this approach. A tolerance for relative counter positioning in the module configuration of $\pm 0.5\text{mm}$ could be baselined. Note that each of the three Cerenkov Counter types should have a unique pin placement, assuring proper stacking of the individual counters into the module form. Final assembly of each module to the overall mechanical support structure could also employ a pinned approach, leading to proper module-to-module alignment as a by-product of assembly. Without details of the design of the overall mechanical support structure, tolerances for module-to-module alignment can only be specified with respect to science requirements, though it would appear that $\pm 1\text{mm}$ should be obtainable with any reasonable design. Standard 'qualified' fasteners are envisioned to secure the individual counters into the module configuration, and also to secure the modules to the overall mechanical support structure.

21. Electrical Interface Requirements

We assume such requirements, including recommended isolation techniques and system grounding scheme, will be levied by the payload on the subsystems. We do not anticipate the Cerenkov system to impose any unusual requirements.

22. Handling Requirements during Calibration, Integration and Test Operations

Basically, the handling requirements during calibration, integration, and testing are similar, and may be driven by the requirements on the Aerogel radiators--noting that the Aerogel materials are highly susceptible to shock and vibration-induced damage. To this end, we are currently investigating a somewhat unique approach for mounting the Aerogel materials in a rigid frame structure. This approach employs a mounting medium of semi-rigid silicone (namely Dow Corning, Sylgard 184) which has the potential to isolate the Aerogel materials from externally induced shock and

vibration inputs at some TBD level. The second area of concern is the 5" Hamamatsu PMT currently baselined for use with the Cerenkov Counters. Additional engineering on this tube is currently in progress in Japan, directed towards improving its shock and vibration characteristics. To date, the following test results have been obtained on the PMT from Hamamatsu:

A). Shock: The tubes were subjected to three impacts at 50g, 11 ms duration each, over 6 axes and remained functional. Additional testing at 75g, 11 ms duration, resulted in the tube experiencing "electrode distribution", and thus, unstable electrical performance. The mesh dynode structure apparently failed mechanically.

B). Vibration: The tubes were subjected to 5g's @ 10-500 hz, 1 Octave/min, with 3 sweeps/axis over 3 axes. The "electrode mounting parts developed deterioration and some of the mesh dynode broke. Electrically, this created unstable performance". Hamamatsu has initiated a program to ruggedize this tube to meet a 75g, 11 ms shock requirement, and a minimum vibration specification of 5g @ 10-500 Hz.

Shock and Vibration Specifications: These are currently TBD. While we anticipate additional data on the Hamamatsu PMT shock and vibration characteristics in the near future, detailed shock/vibration testing of the Aerogel materials has not taken place yet. It is realized that the design of the Cerenkov boxes and their supporting structure will have a significant influence on the shock and vibration environment experienced by both the Aerogel and the PMTs. It can be anticipated that shock-mounted shipping fixtures will be required for the assembled detectors.

Environmental Contamination of Aerogel Materials: The Aerogel materials are susceptible to contamination from both hydrocarbon and water absorption. Water absorption is discussed under the subject of "Humidity Requirements for Storage". Hydrocarbon absorption is less well quantified, though it appears to be a definite source of contamination of the Aerogel materials through an absorption mechanism. A rough estimate of the magnitude of the hydrocarbon concentration leading to contamination under long-term storage (months to years) is of order 10-100 ppm. Higher concentrations lead to more rapid contamination. Lab testing here at Caltech indicates the problem can be minimized through proper selection of materials making up the Aerogel housing or counter; i.e., selection of materials having low hydrocarbon outgassing properties. In addition, externally-generated contamination has been significantly reduced by maintaining the Aerogel storage container, or detector, at a slight overpressure (few inches of water equivalent) with a constant dry-nitrogen flush. Standard grade gaseous dry-nitrogen typically contains no contaminants at the levels of concern, and has the added benefit of providing the proper humidity environment for the Aerogels. A fully sealed system would be another way to approach the problem, particularly during transportation of the counters, (or non-assembled Aerogel materials,) associated with calibration and testing.

Helium Contamination of PMTs: The PMTs must not be subjected to an environment containing more than a few ppm gaseous He (specific concentration TBD) for any extended period. Diffusion of He into the glass envelope of the PMT, through the metal/glass interface at the pins, will lead to rapid deterioration of the PMT performance characteristics. It is noted that Helium concentrations of concern typically exist in association with vacuum leak-testing procedures.

23. Ground Support Requirement during Calibration, Integration and Test Operations

The plan for GSE support for Cerenkov and trigger modules is based on module interface boxes (miffs) which translate the module data output into a standard protocol (first choice is RS-232; second is DEC DR11), and vice-versa -- i.e., from RS-232 to module command input. There will also be stimulus boxes, for stimulating detectors through test inputs, and a power supply, with stimulus control and power control again provided via RS-232. The RS-232 signals can then be transmitted or received by essentially any computer and operating system. We would most likely use Sun Unix workstations. We will work with the other instrument teams and the spacecraft teams to achieve common GSE designs and techniques. It will be necessary to provide access for the stimulus system cables and connectors to the Cerenkov boxes at both assembly and sub-assembly level. The miffs will presumably be used only at sub-assembly level; in the integrated LISA assembly data for the Cerenkov GSE will come from the LISA assembly GSE via some standard link such as Ethernet.

24. Temperature Requirement for Storage

A prime factor affecting the storage temperature specification is the induced stress resulting from differential temperature expansion/contraction between the elements making up the Aerogel mounting scheme currently under development. In the current design concept, a ΔT of $\pm 30^\circ \text{C}$ will result in a differential expansion of about $\pm 1 \text{ mm}$ in the critical components of the Aerogel frame or mounting assembly. If the resulting stress due to this expansion is found to be acceptable, pending testing of our prototype Aerogel assembly, then assuming a nominal assembly temperature of the frame/Aerogel components of 20°C , a storage temperature range of say -10 to $+50^\circ \text{C}$ might be acceptable. However, taking into account the directional component of the induced stress, it is felt that a more conservative range of -10 to $+40^\circ \text{C}$ is more realistic. The lower limit of this range deserves more thought; in general, we see no reason to take the risks associated with storage near or below zero $^\circ \text{C}$.

Note that these specifications are still very preliminary, based on testing yet to be done, and are clearly dependent on the initial assembly temperature and specific materials making up the Aerogel frame assembly.

25. Humidity Requirement for Storage

A nominal humidity range of 10 to 30% RH is currently baselined for storage of the Aerogel materials or assembled Cerenkov Counters. This is driven on the high end by water absorption of the Aerogel materials, which results in reduced light output. On the low end, some shrinkage and embrittlement of both the Millipore filter paper and the tape employed for fastening the paper to the interior of the counter structure is anticipated under long-term, very low humidity storage ($< 10\% \text{ RH}$). While shrinkage and embrittlement is anticipated in the final operating environment of the instrument (i.e., space-vacuum), proper long-term storage prior to final deployment of the instrument should reduce the overall effect. Additional testing is required to quantify the magnitude of this effect, and to qualify the proposed materials for a long-term vacuum environment. It is noted that a nominal humidity range of 10 to 30% RH is easily maintained here at Caltech for Aerogel storage, using a simple dry-nitrogen flushing

system. While other materials are currently under test as possible replacements for the Millipore, this material is currently baselined for use in the counters.

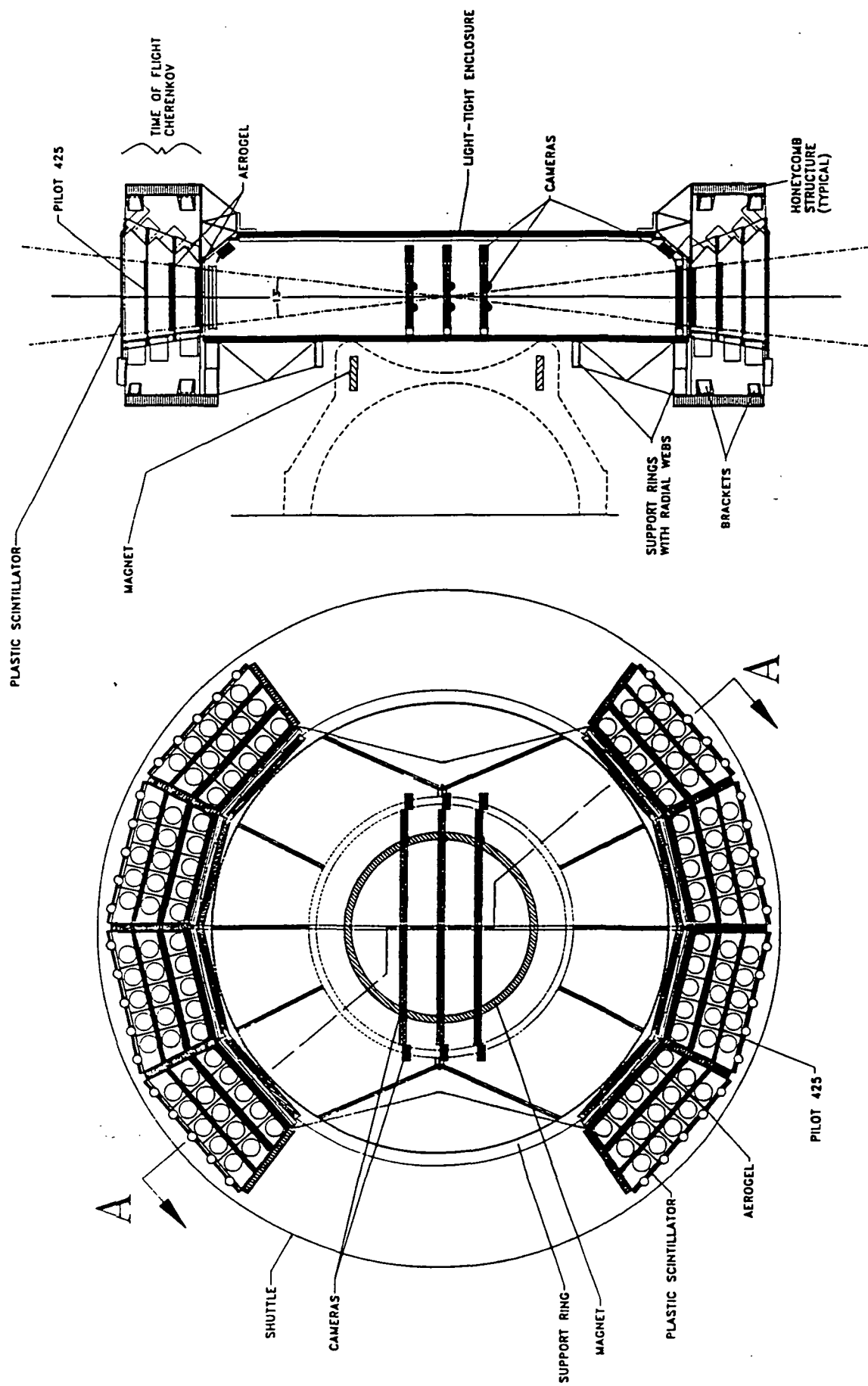
26. Alternate Cerenkov Counter Designs

In the period since the proposal was written we have learned that it will be possible to get somewhat larger aerogel blocks. We presently estimate (conservatively) that the largest size available for an index of $n=1.03$ might be about 48 cm x 48 cm, while the dimension of $n=1.04$ blocks might be about 50 x 50. This might translate to "active areas" of 46 x 92 for $n=1.03$ and 48 x 96 for $n=1.04$. To accommodate these larger blocks we would want to increase the size of the Cerenkov boxes accordingly. Coupled with this increase in size it is also desirable to consider going to a design with three modules on top and bottom.

To estimate the size of the required boxes for these larger aerogel blocks it is only necessary to add 4 cm to all dimensions in Figure 4 (except the height of the box). This gives frame sizes of 50x95 and 54x103. This assumes that we put the $n=1.03$ blocks closest to the center, which might not be optimum. If we do go to larger aerogel blocks and a 3-segment design, it is likely that we will also try to go to six PMTs per side to compensate for the larger boxes. This would still lead to a reduction in the overall number of tubes from 240 to 216. Figure 7 shows a side view of the proposed three segment design with larger aerogels. The aerogel active areas and frames are illustrated. The assumed usable areas are 46x92 for $n=1.03$, 48x96 for $n=1.04$, and ~60x118 for the Pilot-425.

There are also other considerations. In the design shown in the proposal all blocks are on the "inside" surface of the box. This probably maximizes the geometry factor, and provides some information on particle direction that may be useful in anti-nuclei studies. However, we expect that we may achieve greater light collection by always having the aerogel on the surface through which the particle enters (the top of the box). We do not yet know the magnitude of this effect but will be measuring it in a similar geometry. Another possibility, shown in Figures 2 and 4, is to have the aerogels back to back. This minimizes the effect of the 3-cm wide gap down the center of the counter. Each of these possible arrangements will have implications for the geometry factor which need to be calculated.

We also need to rethink whether the $n=1.04$ should be on the inside (as in the proposal) if it is larger than the $n=1.03$. One case seems to maximize the number of good events from 2.4 to 2.9 GeV/nuc, while the other maximizes events from 2.9 to 3.5 GeV/nuc (those triggering all 4 counters).



SECTION A-A

Figure 1

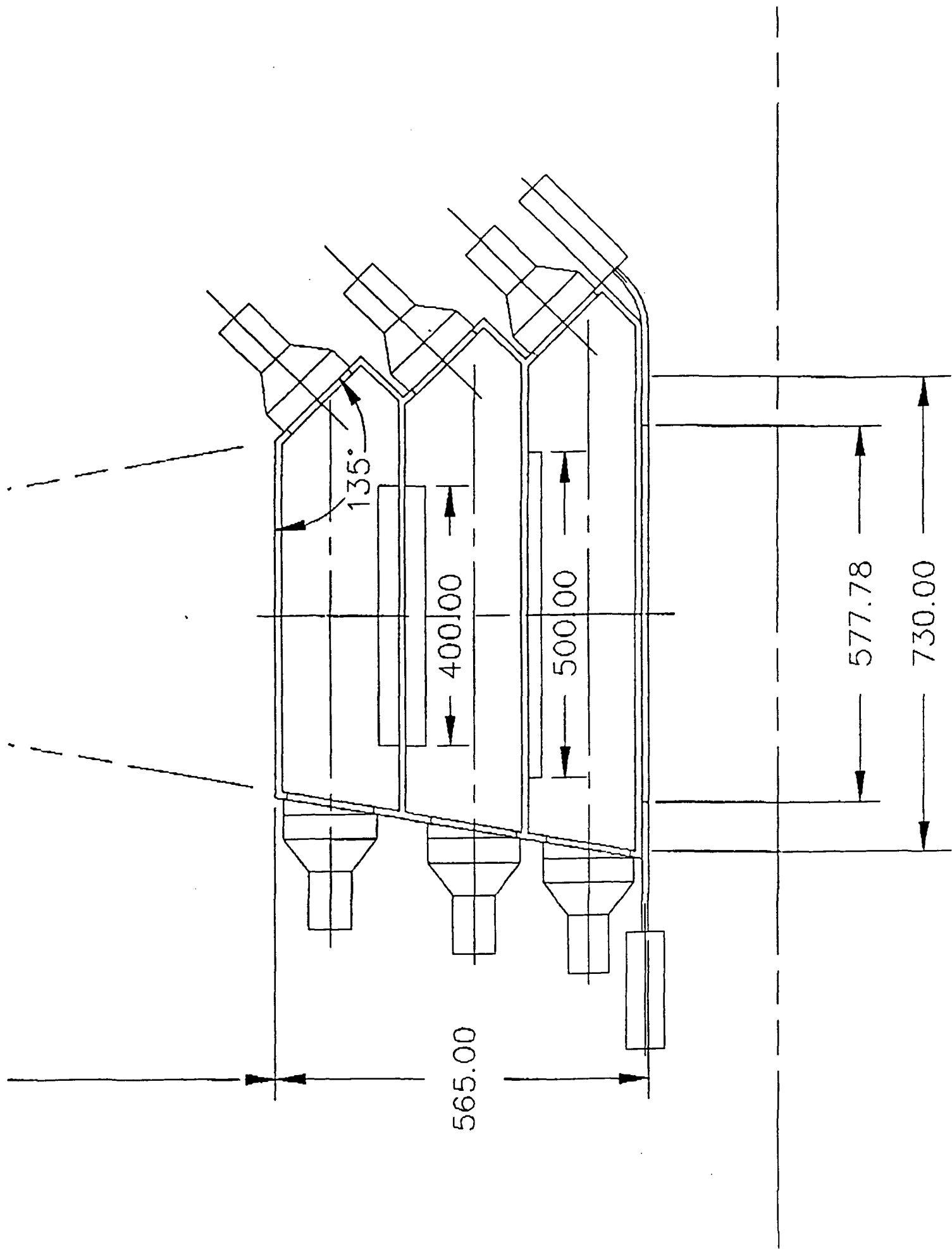


Figure 2

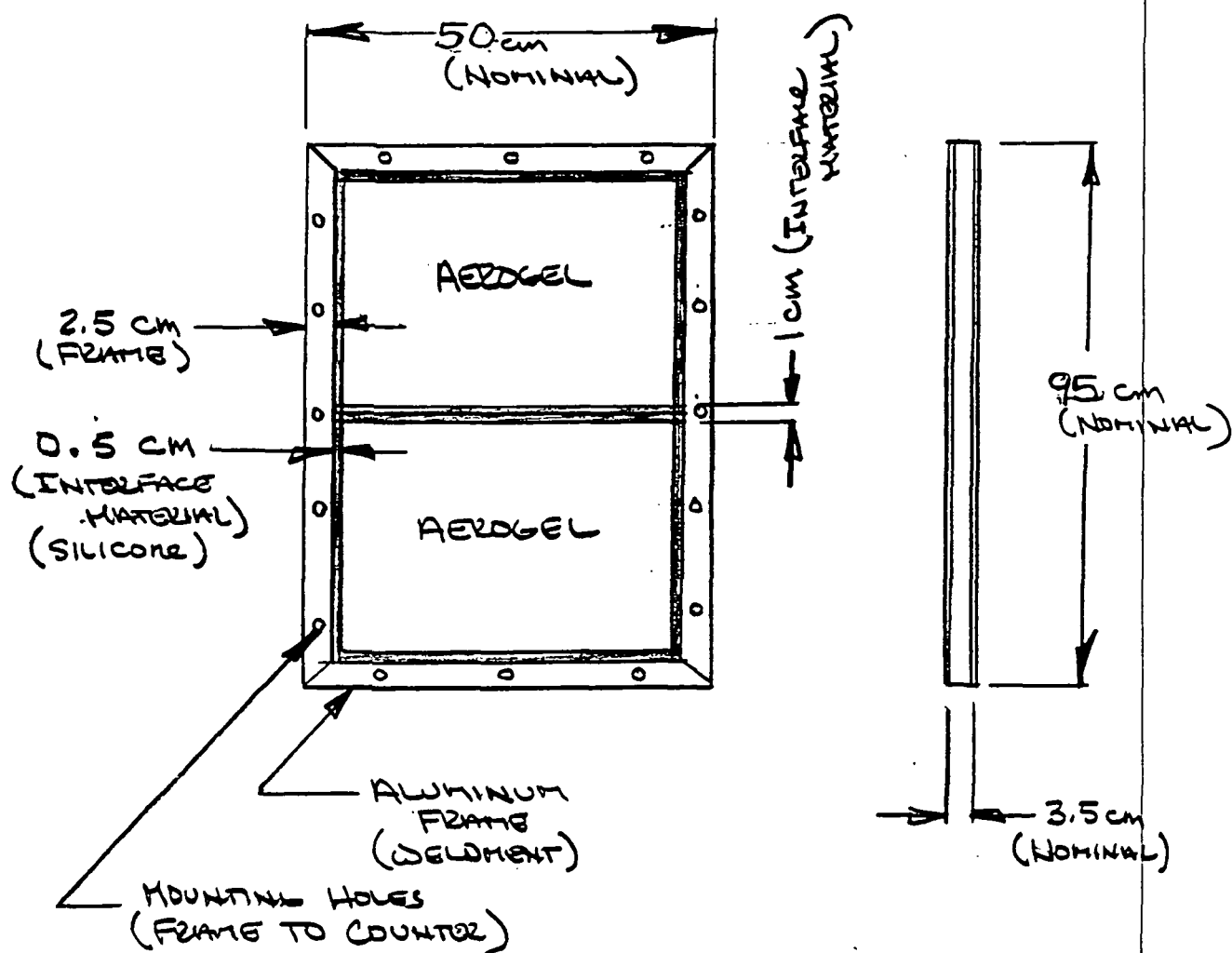


Figure 3

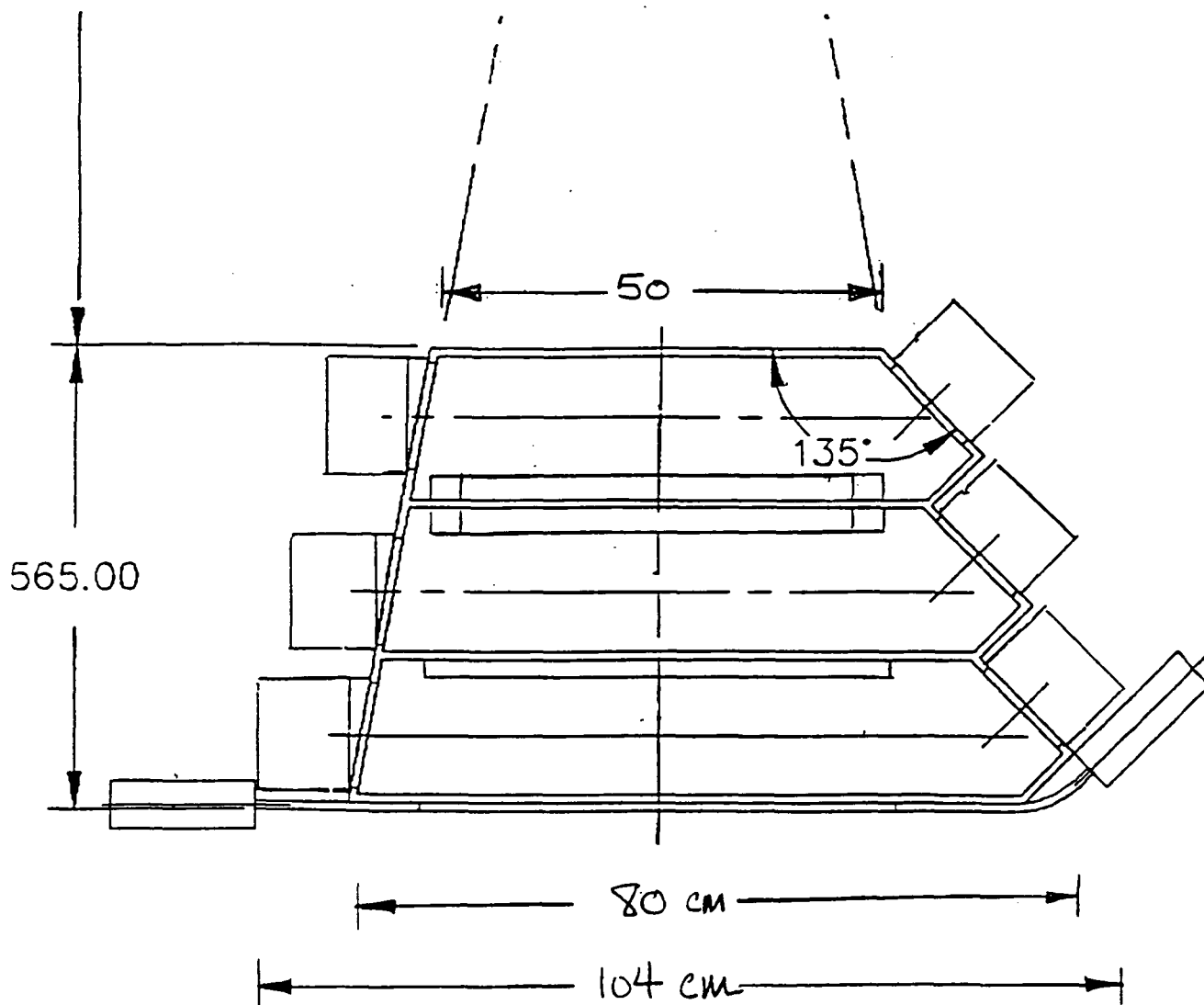
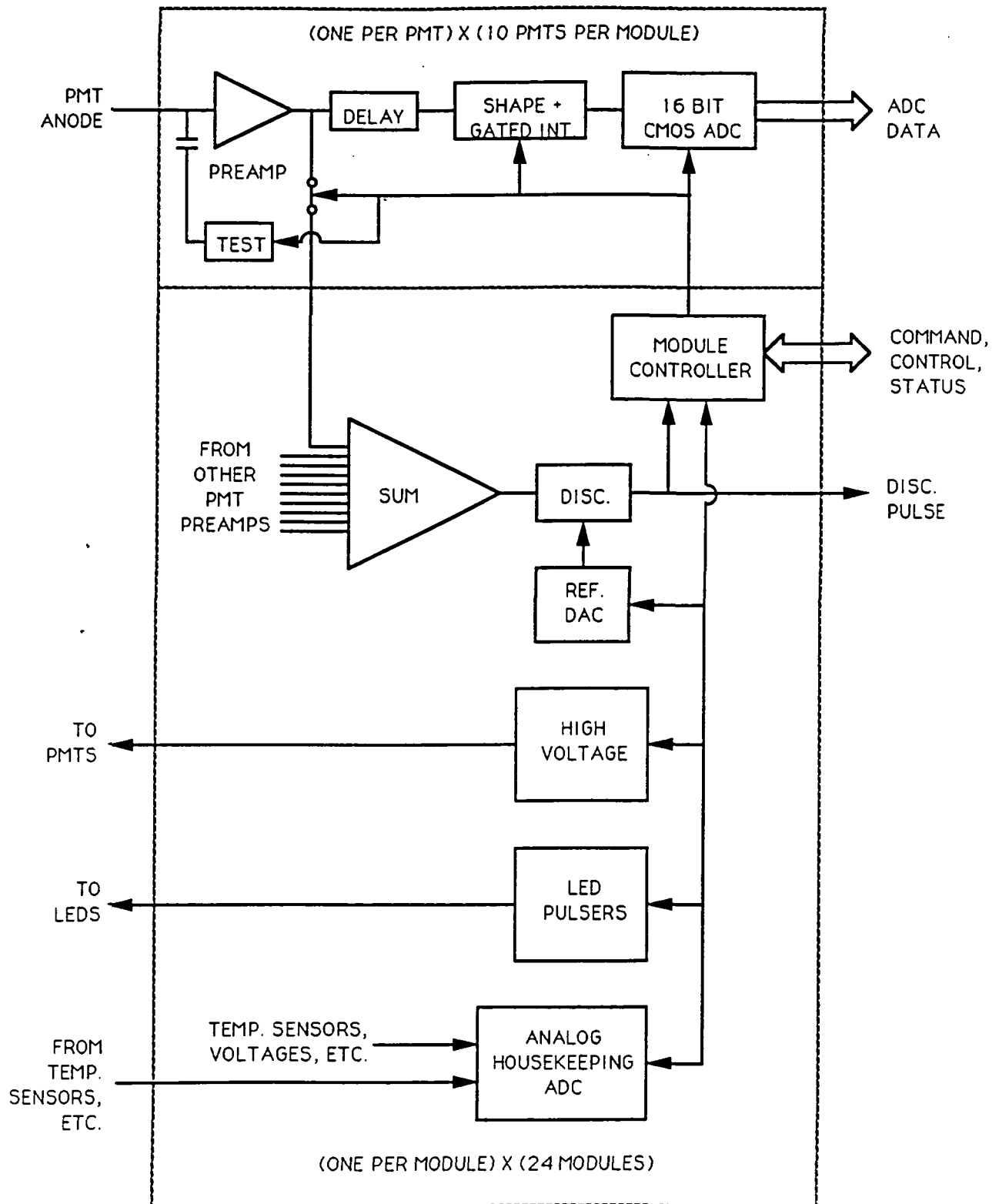


Figure 4

Figure 5

CERENKOV MODULE ELECTRONICS



CERENKOV ELECTRONICS OVERVIEW

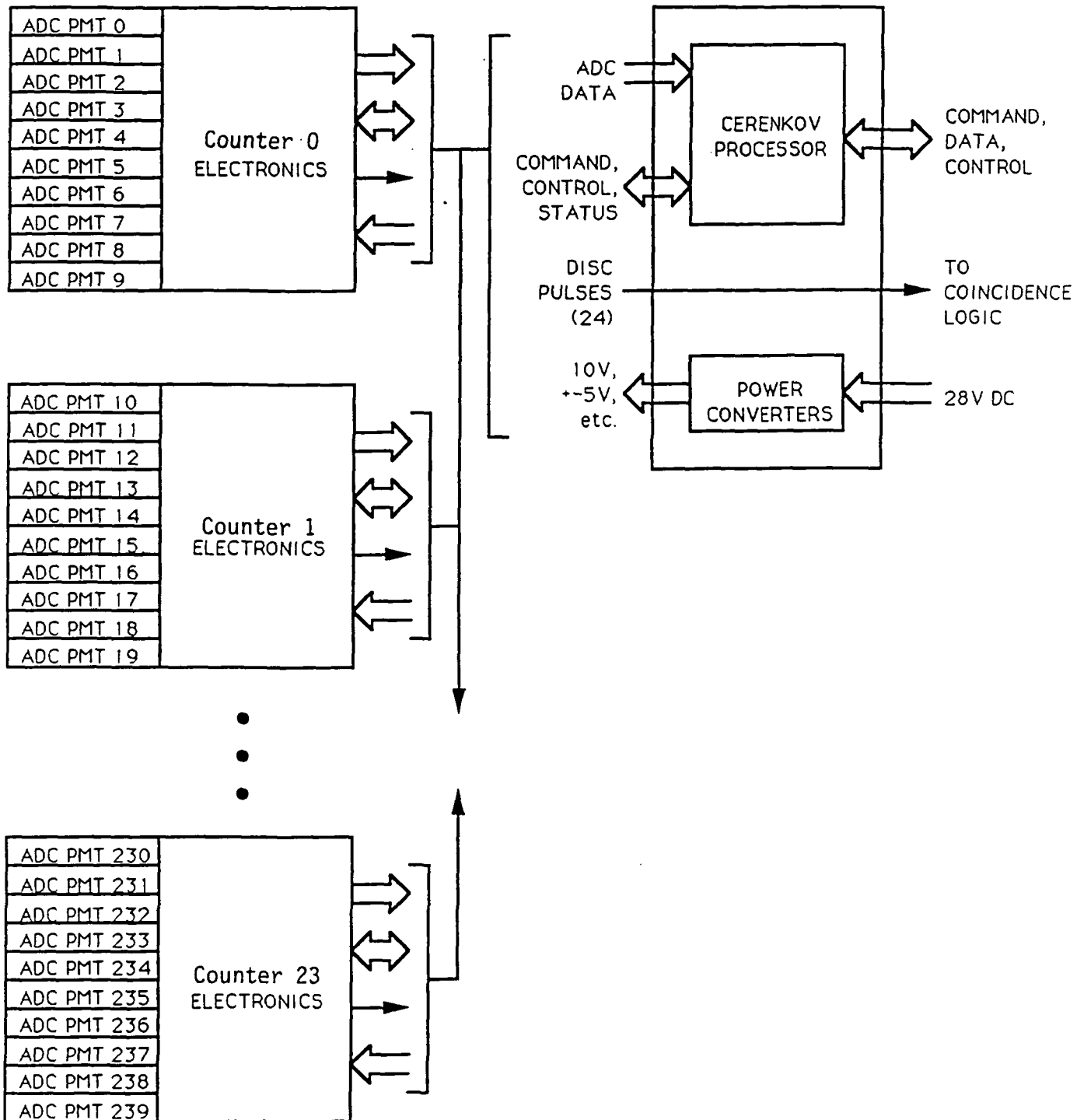


Figure 6

Figure 7

Proposed 3-Segment Design
(Single Segment Shown)